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STRATIGRAPHY OF THE NEOPROTEROZOIC ARUHNA AND DEPOT SPRINGS SUBGROUPS, ADELAIDE GEOSYNCLINE

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Summary

DYSON, I. A. (1996) Stratigraphy of the Neoproterozoic Aruhna and Depot Springs subgroups, Adelaide Geosyncline. *Trans. R. Soc. S. Aust.* (1996), **120**(3), 101-115, 29 November, 1996.

The Sandison Subgroup of the Lower Wilpena Group is unconformably overlain by the Wilcolo Sandstone and, together with the Bunyeroo Formation, comprises the Aruhna Subgroup. The Bunyeroo Formation is in turn unconformably overlain by the Wearing Dolomite which, together with the overlying Wonoka Formation, is assigned to the Depot Springs Subgroup. A number of subgroups in the Umberatana and Wilpena groups is also capped by dolostones that display similar characteristics to the Wearing Dolomite of the Depot Springs Subgroup. The dolostones are interpreted as having been deposited on major, sediment-starved hiatal surfaces under cold water conditions, each of which is adjacent to either a major incised valley or submarine canyon fill. The differentiation of these unconformity-bounded subgroups is based on their recognition as genetic units in terms of sequence stratigraphy.

KEY WORDS: Sequence stratigraphy, Neoproterozoic, Aruhna Subgroup, Depot Springs Subgroup, Bunyeroo Formation, Wearing Dolomite, Burr Well Member, Artipena Dolomite Member, Wilcolo Sandstone, Wonoka Formation, incised valleys, submarine canyons, dolostones, Adelaide Geosyncline.

Introduction

The stratigraphic nomenclature of the Adelaide Geosyncline emphasises the distinction between chronostratigraphic and lithostratigraphic units (Preiss 1987a). The positions of the chronostratigraphic units do not always correspond to lithostratigraphic boundaries. Some lithostratigraphic boundaries are unconformities and therefore assume chronostratigraphic significance, while others are mappable lithological changes of regional significance (Preiss 1987a). These differences between the two stratigraphies can best be accommodated by adopting a sequence stratigraphic scheme. It depends on the recognition of mappable rock units within a chronostratigraphic framework of repetitive, genetically-related strata bounded by unconformities or their correlative conformities. Thus, a revised stratigraphic nomenclature of Neoproterozoic successions in the Adelaide Geosyncline could be based on differentiation of subgroups within a sequence stratigraphic framework (Dyson 1992a, b, 1996a). Forbes & Preiss (1987) suggested there was merit in uniting related depositional units in a single subgroup.

Sequence analysis of the Umberatana Group (Dyson 1992a, 1995[1], 1996a, b) and Wilpena Group (von der Borch *et al.* 1988; Dyson 1992b) has led to the recognition of several unconformity-bounded depositional sequences. In a study of the Sandison Subgroup (Dyson 1995[1]), stratigraphic units immediately overlying this sequence were examined in order to understand better the spatial and temporal relationships of the Lower Wilpena Group. The Sandison Subgroup is unconformably overlain by the Wilcolo Sandstone and together with the Bunyeroo Formation is herein assigned to the Aruhna Subgroup. Similarly, the Bunyeroo Formation is unconformably overlain by the Wearing Dolomite and together with the Wonoka Formation is assigned to the Depot Springs Subgroup. The Sandison, Aruhna and Depot Springs subgroups (Fig. 1) are defined as genetic units that are considered major unconformity-bounded, depositional sequences in the sense of Mitchum (1977). Of particular significance is the nature of the Wearing Dolomite and its relationship to other Neoproterozoic dolostones or units that contain appreciable dolomite in the Adelaide Geosyncline, i.e., Nuccaleena Formation, Tindelpina Shale, Warcowie Dolomite and the Artipena Dolomite Member (new name) of the Enorama Shale. The names "Wilcolo Sandstone", "Aruhna Subgroup", "Depot Springs Subgroup" and "Artipena Dolomite Member" have been reserved by the Central Register of Australian Stratigraphic Names.

Aruhna Subgroup

In the southern and central Flinders Ranges, the ABC Range Quartzite is overlain with local

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[1] DYSON, I.A. (1995) Sedimentology and stratigraphy of the Neoproterozoic Sandison Subgroup: a storm-dominated shallow marine sequence in the Adelaide Geosyncline, South Australia. PhD thesis, Flinders University of South Australia (unpub.).

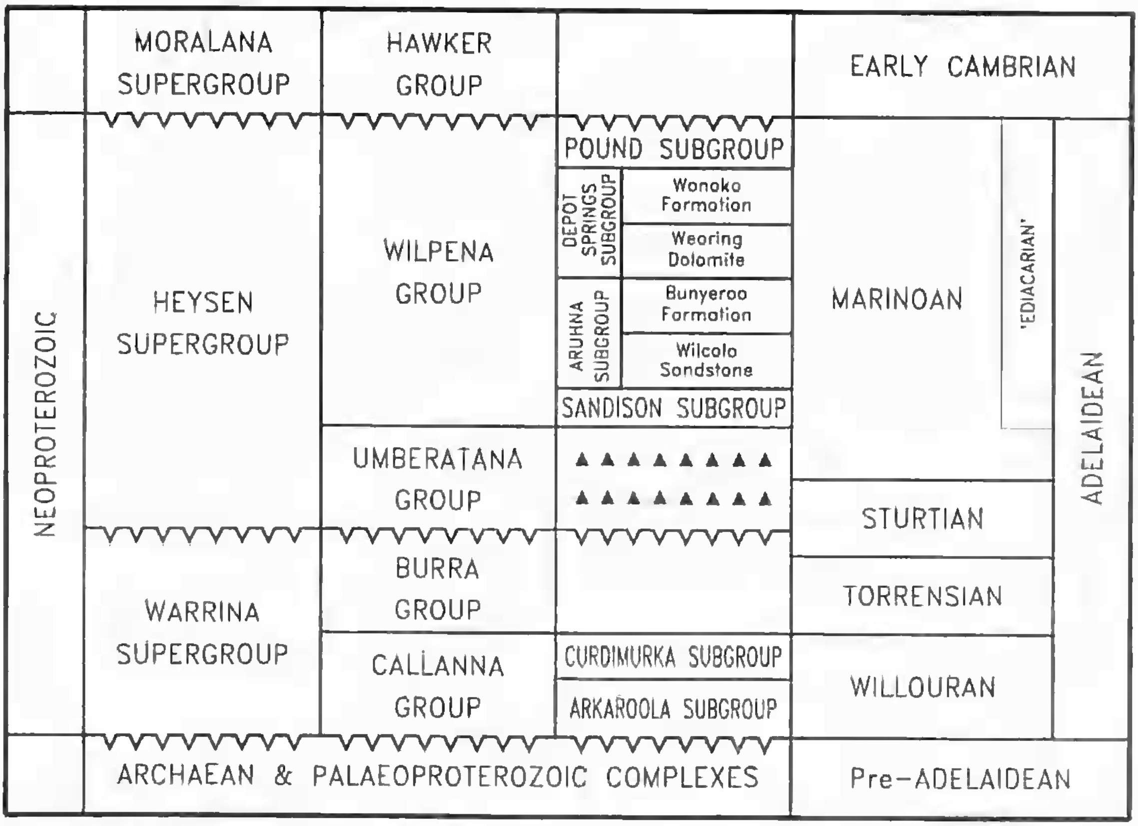

Fig 1. Stratigraphy of the Aruhna Subgroup and Depot Springs Subgroup with respect to selected lithostratigraphic units of the Adelaide Geosyncline. Note the stratigraphic position of dolostones within the Umberatana and Wilpena Groups.

disconformity by a thin (2-5 m), massive, purple, coarse-grained to pebbly cross-bedded sandstone of fluvial origin (Plummer 1978). In places, it is interbedded with conglomerate and purple shale. It is, in turn, overlain by greyish red shale and thin, interbedded lenticular sandstone of the Bunyeroo Formation with a sharp, conformable contact. Dyson (1992b, 1995[1]) recognised the regional significance of this unconformity and the nature of the channel-fill facies overlying the unconformity. The channel-fill facies is referred to herein as the Wilcolo Sandstone and is conformably overlain by shale of the Bunyeroo Formation.

The Wilcolo Sandstone and Bunyeroo Formation together constitute the Aruhna Subgroup (Fig. 2). It is a third-order cycle that is overall transgressive and was deposited during one eustatic fall and rise of relative sea level. A reference section is designated in Bunyeroo Valley between Aroona Ruins and Wilcolo Creek on PARACHILNA. The Aruhna Subgroup was studied at Bunyeroo Gorge, Mount Terrible, Partacoona, Pettana Gorge, Trebilcock Gap and the Mount Goddard and Angepena Synclines (Fig. 3). A type section for the Wilcolo Sandstone (Fig. 4) is designated in Wilcolo Creek, 2 km south of Bunyeroo Gorge (lat. 31° 25′ 10″ S, long. 138° 33′ 12″ E).

Lower sequence boundary

The Wilcolo Sandstone represents an incised valley fill near the top of the ABC Range Quartzite. A shallow palaeovalley can be traced from the Aroona Valley (30 m thick) to south of Bunyeroo Gorge where it attains a thickness of 3 m (Fig. 4). The base of the incised valley fill is interpreted to be a sequence boundary that was cut during a lowstand of relative sea level. At Partacoona (Fig. 3), the base of the incised valley is interpreted as a combined sequence boundary/transgressive surface. A possible sequence boundary exists near the top of the ABC Range Quartzite at Hidden Gorge (Fig. 3). Here, the sequence boundary is overlain by a thick (> 10 m), very coarse-grained sandstone or conglomerate that is typically bimodal and very well-sorted. Internally, diagenetic chert occurs as replacements and overgrowths. The same texture is observed in the Wilcolo Sandstone near Bunyeroo Gorge.

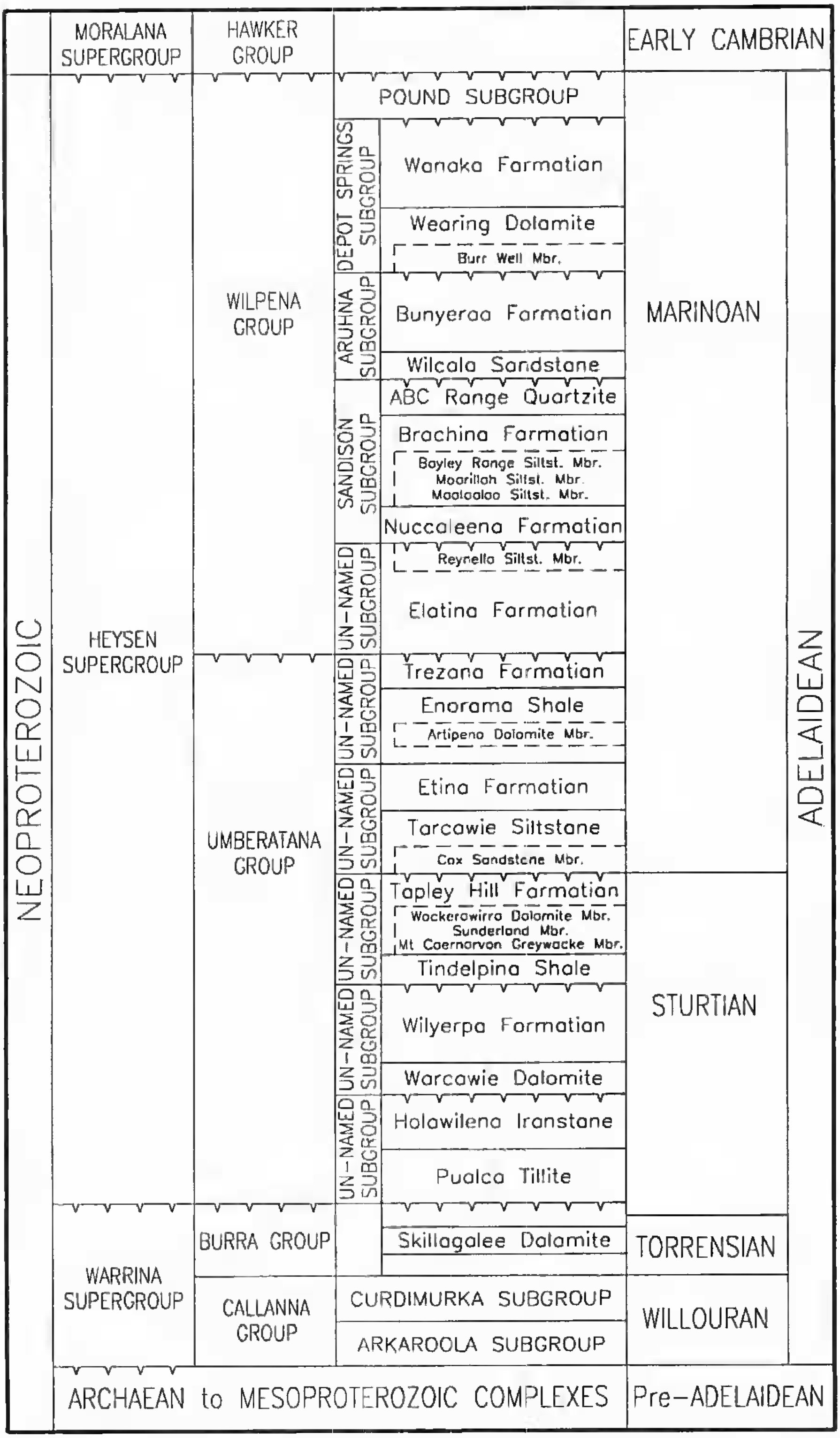

Fig. 2. Unconformity-bounded subgroups conforming to depositional sequences in the Umberatana Group and lower Wilpena Group (after Dyson 1995[1]).

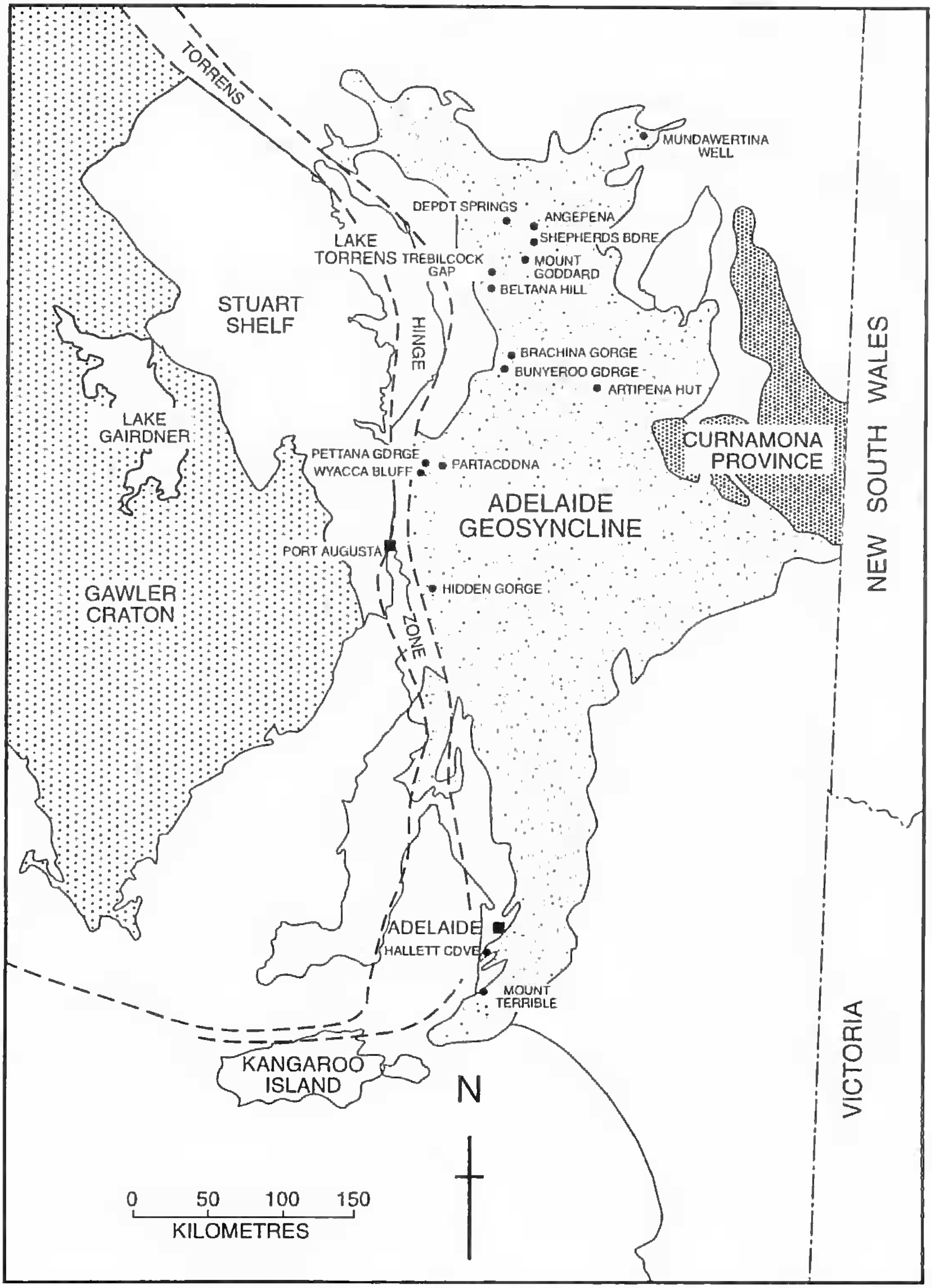

Fig. 3. Tectono-sedimentary provinces of eastern South Australia, showing localities of stratigraphic sections in the Adelaide Geosyncline and their relation to other localities on the Stuart Shelf and in the Torrens Hinge Zone (after Dyson 1995[1]).

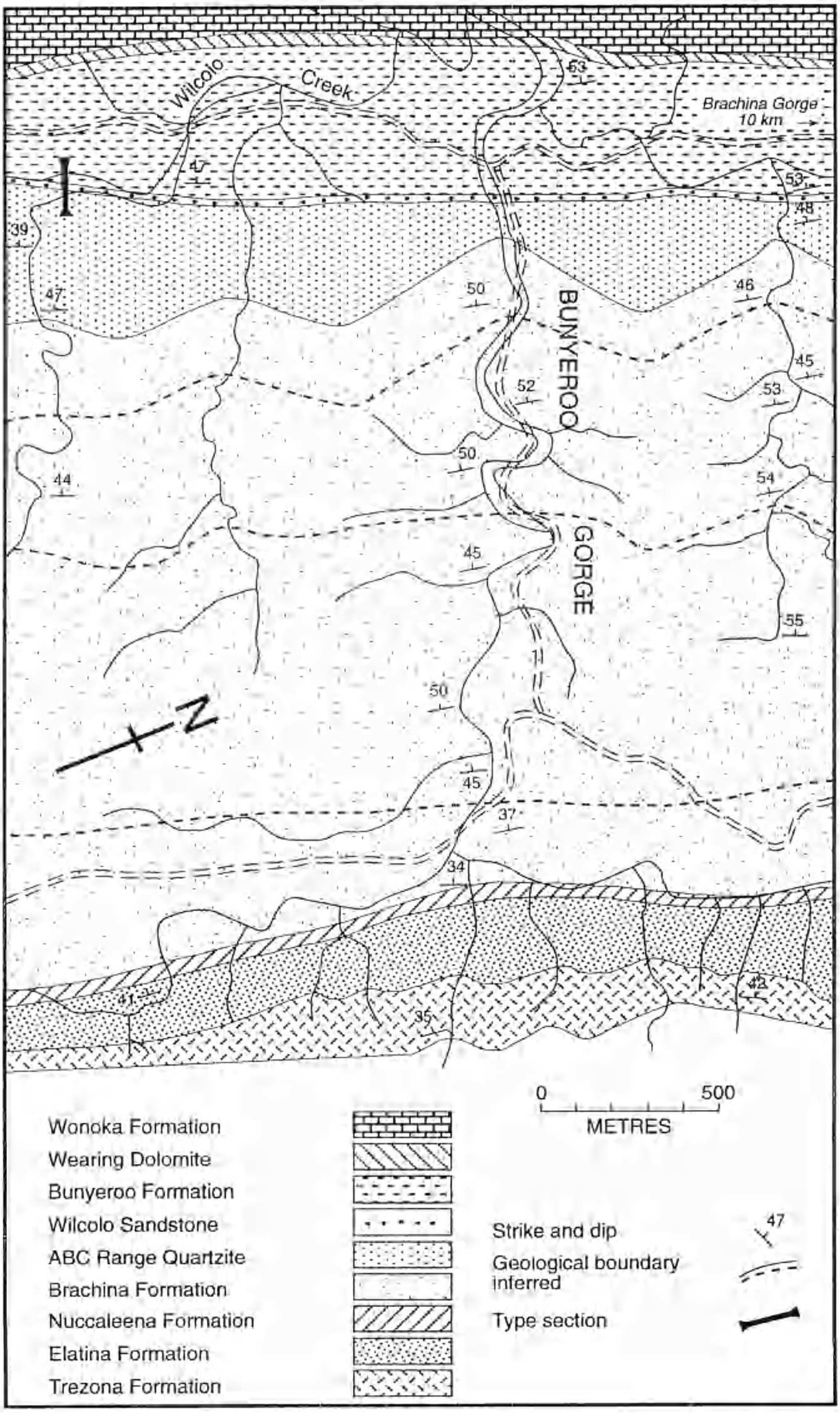

Fig. 4. Geological map of the lower Wilpena Group at Bunyeroo Valley showing the type section for the Wilcolo Sandstone (after Dyson 1995).

Fig. 5. Pebbly cross-bedded sandstone (2 m thick) of fluvial origin, assigned to the Wilcolo Sandstone, overlying shallow marine sediments of the ABC Range Quartzite about 2 km south of Bunyeroo Gorge. The channelised base of the sandstone is immediately left of the native pine in the centre foreground.

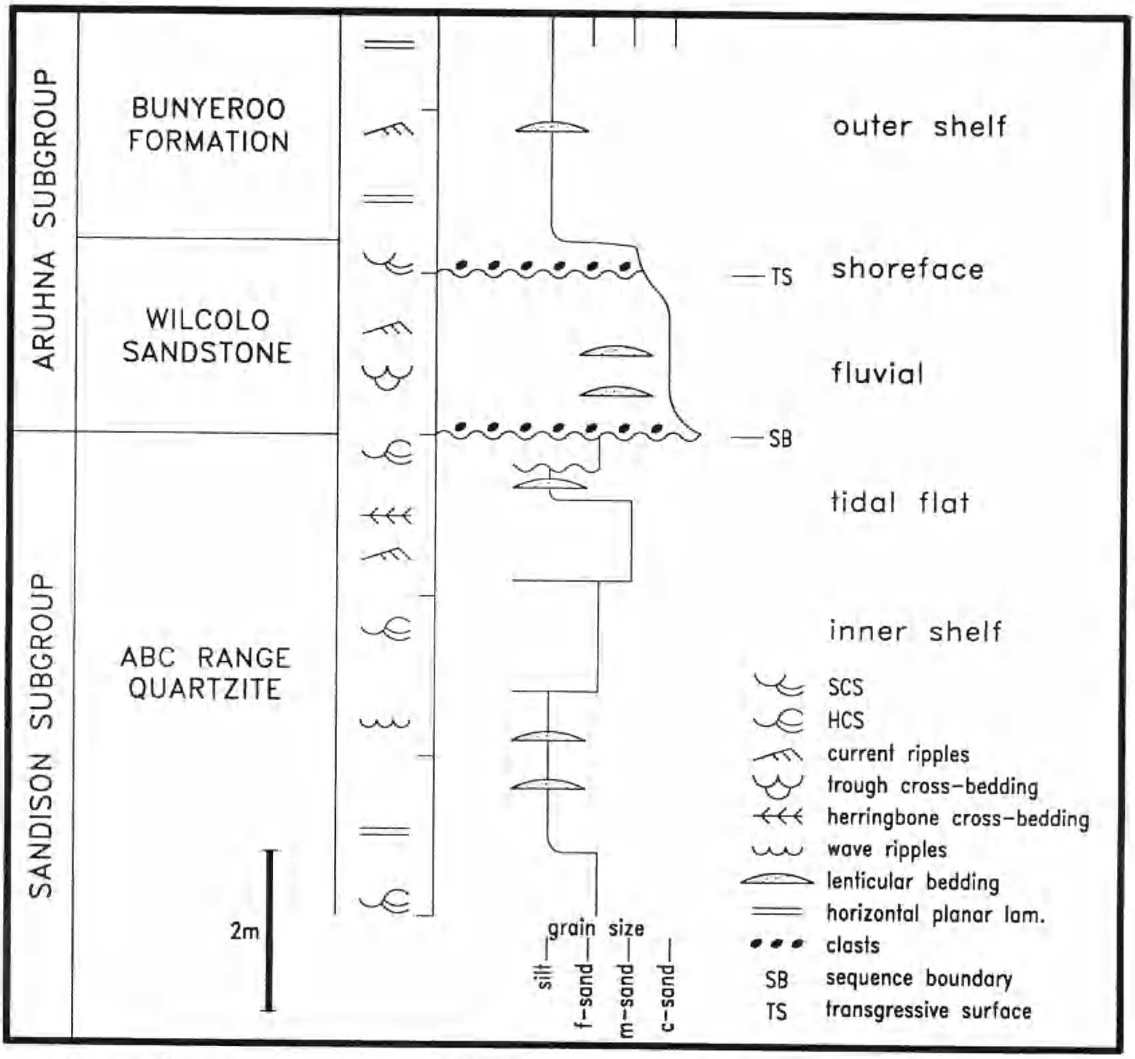

Fig. 6. Stratigraphic log of the Wilcolo Sandstone at the proposed type section, south of Bunyeroo Gorge.

Fig. 7. Fluvial channel at the base of the Wilcolo Sandstone is overlain by a 20 cm-thick mature sandstone that is in turn gradationally overlain by shale of the Bunyeroo Formation. The head of the hammer marks the sharp contact between the two sandstones, interpreted as the transgressive surface.

Wilcolo Sandstone

The fluvial channel at the base of the Wilcolo Sandstone (Fig. 5) near Bunyeroo Gorge is overlain by a thin (c. <1 m), mature sandstone (Figs 6, 7) that often displays swaley cross-stratification (SCS), hummocky cross-stratification (HCS) and symmetrical ripples (Dyson 1992b). The base of the swaley cross-stratified sandstone is interpreted as a transgressive surface. At Partacoona, an unconformity at the top of the ABC Range Quartzite is overlain by 25 m of mature, off-white quartzite that displays trough cross-bedding of tidal origin and large symmetrical wave ripples with abundant well-rounded clasts of gravel to pebble size. The quartzite was deposited in a possible incised valley of similar dimensions to that observed in the Aroona and Bunyeroo valleys. A contact with overlying shale of the Bunyeroo Formation was not observed. Near Trebilcock Gap west of Beltana, the Wilcolo Sandstone varies in thickness from 20-50 m where it consists of interbedded metre-thick, pebble to cobble conglomerate, medium to coarse-grained sandstone and shale. The conglomerate and sandstone display planar-tabular cross-bedding and SCS respectively, and are interpreted as having been deposited in a shoreface environment within an incised valley fill. About 1.5 km either side of Trebilcock Gap, the incised valley fill contains large (500 x 100 m) rafts of diapiric breccia, thought to have slumped into the incised valley during the early stages of deposition. On the south limb of the Mount Goddard Syncline, a greyish red, fine-grained sandstone erosively overlies the Ulupa Siltstone. The sandstone, about 1 m thick, contains angular to sub-rounded clasts of diapiric material suggesting exposure of a nearby diapir and is interpreted as being of fluvial origin (Fig. 8).

At Pettana Gorge (Fig. 3), the Wilcolo Sandstone is absent but for a thin remnant of gritty and gossanous sandstone. It is erosively overlain by a boulder conglomerate at the base of a submarine canyon in the Wonoka Formation (Dyson 1995[1]), not mapped previously on ORROROO (Binks 1968). The base of the Wilcolo Sandstone is not exposed at Hallett Cove (Fig. 3), but at Mount Terrible it is overlain by interbedded greyish red siltstone and mature sandstone. At this locality, the base of the Wilcolo Sandstone is interpreted as a combined sequence boundary/transgressive surface. A similar situation exists at Finke Springs on the north limb of the Angepena Syncline where a thick-bedded, medium-grained, swaley cross-stratified sandstone of shoreface origin overlies the ABC Range Quartzite. On the south limb of the Angepena Syncline near Shepherds Bore (Fig. 3), a decimetre-thick, tidally

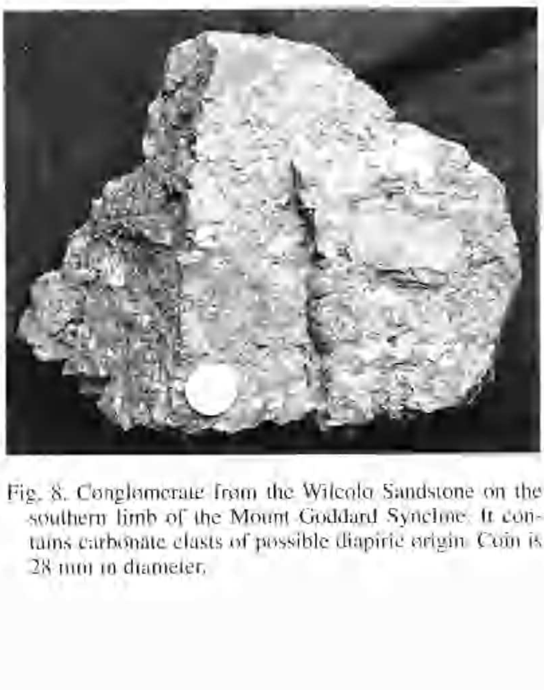

Fig. 8. Conglomerate from the Wilcolo Sandstone on the southern limb of the Mount Goddard Syncline. It contains carbonate clasts of possible diapiric origin. Coin is 28 mm in diameter.

cross-bedded sandstone erosively overlies the Ulupa Siltstone. It is overlain by a 30 m-thick section of interbedded greyish red shale and sandstone that grades upward into reddish shale of the Bunyeroo Formation.

Bunyeroo Formation

The Bunyeroo Formation (Dalgarno & Johnson 1964) is 700 m thick in its type section at Brachina Gorge (Fig. 3), where it consists of laminated to massive, dark reddish brown shale. The overall upward-fining succession is punctuated by a series of subtle, upward-coarsening cycles that in places range from 5-10 m thick. Sedimentary structures associated with very fine to fine-grained sandstone at the top of some cycles include small-scale cross-bedding and micro-HCS.

The Bunyeroo Formation was for the most part deposited below storm wave base in a middle to outer shelf setting. Dyson (1992b) placed the Bunyeroo Formation in a transgressive systems tract that was capped by the former Wearing Dolomite Member of the Wonoka Formation.

Upper sequence boundary

The sequence boundary at the top of the Bunyeroo Formation is coincident with the former Wearing Dolomite Member of Thomson (1965). It is elevated herein to formation status to reflect its regional significance. Deposition of the Wearing Dolomite is interpreted as having been contemporaneous with the canyon unconformity at the base of the Wonoka Formation (Dyson 1995[1], 1996a, b).

Depositional environment

The Wilcolo Sandstone was deposited in a fluvial and estuarine to shallow marine environment. The Bunyeroo Formation was deposited in progressively deeper water in a middle to outer shelf setting and constitutes a transgressive systems tract. Thus, sedimentation of the Aruhna Subgroup was unable to keep up with subsidence, resulting in a depositional transgression in the sense of Curray (1964). The Bunyeroo Formation thickens eastward of the Torrens Hinge Zone (Fig. 3). Adjacent to diapirs, onlapping sediments of the Aruhna Subgroup are thin. However, localised thick development of the Bunyeroo Formation occurs adjacent to some diapirs. A thick, black succession of sulphide-rich shale adjacent to the Mucatoona Diapir (Coats 1973) suggests anoxic, deep water deposition of the Bunyeroo Formation, perhaps associated with the formation of a crestal graben over the diapir due to salt depletion. The diapirs of the Flinders Ranges often contain volcanic xenoclasts (Preiss 1987b), and Coats (1973) suggested that many diapirs on COPLEY were active and exposed during deposition of the basal Bunyeroo Formation. An inferred volcanic component of the redbeds (Mawson 1939; Plummer 1978a) may be related to depositional onlap of Bunyeroo sediments adjacent to exposed diapirs.

Dalrymple (1992) suggested that estuarine sandstones were transgressive in origin because estuaries owed their existence to marine flooding of incised valleys. On the other hand, Exxon researchers (e.g., Van Wagoner *et al.* 1987) argued that fluvial sediments at the base of incised valleys should be assigned to the lowstand systems tract deposited during an initial fall and subsequent early rise of relative sea level. Alternatively, such fluvial units may be the updip equivalent of transgressive marine sandstones. The lack of beach deposits between the fluvial and estuarine sandstones of the Wilcolo Sandstone at Bunyeroo Gorge suggests that the base of the estuarine sandstone is the transgressive surface. The ensuing transgression eroded and reworked the former beach sediments.

Depot Springs Subgroup

The Wonoka Formation (Dalgarno & Johnson 1964) and Wearing Dolomite together represent a transgressive-regressive (T-R) cycle that is referred to as the Depot Springs Subgroup (Fig. 1). The Depot Springs Subgroup constitutes an unconformity-bounded depositional sequence and was studied at a number of localities on PARACHILNA, COPLEY and MARREE including Pettana Gorge, Wyacca Bluff, Brachina Gorge, Bunyeroo Gorge, Beltana Hill, Mount Goddard, Shepherds Bore and Mundawertina Well (Fig. 3). A reference section for the subgroup is designated in and adjacent to the Patsy Springs canyon of the Angepena Syncline near the Depot Springs H.S., 40 km east of Copley (Fig. 3).

The base of the Wonoka Formation was mapped on PARACHILNA (Dalgarno & Johnson 1966) where a colour change occurred above greyish red sandstones at the top of the underlying Bunyeroo Formation. This boundary corresponded to a rather abrupt increase in lime content. Gostin & Jenkins (1983) defined a decimetre-thick dolostone overlying reddish shales of the Bunyeroo Formation, referred

HAINES, P.W. (1987) Carbonate shelf and basin sedimentation, late Proterozoic Wonoka Formation, South Australia. PhD thesis, University of Adelaide (unpub.).

DI BONA, P.A. (1989) Geologic history – sequence stratigraphy of the late Proterozoic Wonoka Formation, northern Flinders Ranges South Australia. PhD thesis, Flinders University of South Australia (unpub.).

Fig. 9. Sharp contact between the Bunyeroo Formation and Wearing Dolomite in the Angepena Syncline. The Wearing Dolomite is about 30 cm thick. Its base is marked by the head of the hammer with sedimentary facing to the right.

Fig. 10. Wearing Dolomite displaying micro-HCS, Angepena Syncline.

to informally as the Wearing Dolomite Member (Thomson 1965), as the base of the Wonoka Formation. Jenkins (1993) defined the base of the Wonoka Formation in Bunyeroo Gorge at the base of an intraformational conglomerate within the Wearing Dolomite Member. Haines (1987[2]) divided the Wonoka into 11 lithofacies units. These units were subsequently adopted by other workers (e.g., Di Bona 1989[3]; Christie-Blick *et al.* 1990) with the prefix W.

Lower sequence boundary

The base of the Wearing Dolomite is defined as a sequence boundary. It can be either sharp or diffuse in nature. Jenkins (1993) interpreted a sequence boundary at the base of an intraformational conglomerate within the Wearing Dolomite. However, the intraformational conglomerate displays edgewise clasts that have in the past been interpreted as storm rosettes (e.g., Dyson & von der Borch 1986). Dyson (1992b) suggested that the Wearing Dolomite represented deposition within a condensed section that included a possible maximum flooding surface. Furthermore, the Wearing Dolomite was deposited on a sediment-starved hiatal surface below storm wave base (see below).

Wearing Dolomite

The former Wearing Dolomite Member of Thomson (1965) is a thin cream, dolostone or dolomitic siltstone that has been mapped over extensive areas of the Flinders Ranges (Forbes & Preiss 1987). It corresponds to unit 1 of Haines (1987[2]). The Wearing Dolomite often sharply overlies the Bunyeroo Formation with apparent

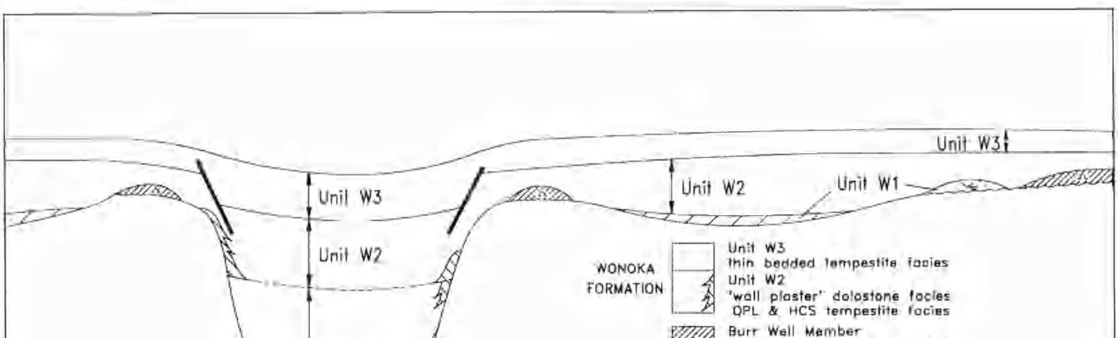

Fig. 11. Schematic cross-section through the Patsy Springs Canyon in the Angepena Syncline (after Dyson 1995[1]). Note the relationship between dolostones of the Wearing Dolomite.

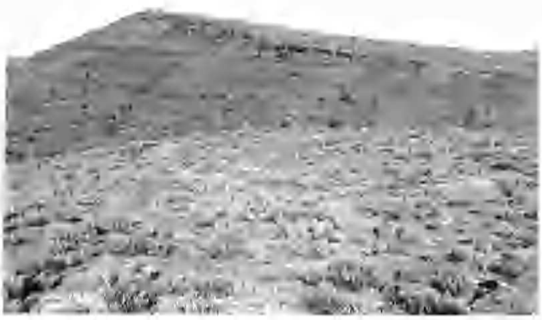

Fig. 12. Brecciola limestone of the Wearing Dolomite unconformably overlying the Bunyeroo Formation east of Beltana Hill.

conformity (Fig. 9). It is characterised by wavy to parallel lamination and, less commonly, by micro-HCS (Fig. 10). A similar situation exists on the south limb of the Angepena Syncline and north limb of the Mount Goddard Syncline. Near Mundawertina Well and on the northern limb of the Angepena Syncline, the Wearing Dolomite splits into two thin dolostones that are separated by up to 25 m of laminated grey green shale. At Pettana Gorge (Fig. 3), a 2 m-thick boulder conglomerate cuts downward into the ABC Range Quartzite. It marks the base of a shallow canyon with an estimated relief of 70 m. About 5 km south of Pettana Gorge near Wyacca Bluff, the Bunyeroo Formation attains a thickness of about 50 m where it is sharply overlain by a decimetre-thick dolostone of the Wearing Dolomite with a sharp, planar contact. It is interpreted as the correlative conformity adjacent to the submarine canyon.

Other dolostones are also genetically related to the Wearing Dolomite at this stratigraphic level (Fig. 11). About 2 km east of Beltana Hill (Fig 3), the Wearing Dolomite passes laterally into a several metre-thick, cream to orange laminated dolostone that is often brecciated and present as detached slump blocks (Leeson & Nixon 1966). Here, it overlies reddish shales of the Bunyeroo Formation with an angular unconformity (Fig. 12). This dolostone is thought to represent the "wall plaster veneer" of Eickoff (1988[1]). A similar relationship can also be observed near Mundawertina Well, and also on the south limb of the Angepena Syncline where the Wearing Dolomite can be traced into slumped wall plaster at the edge of the Patsy Springs canyon (Dyson 1995[1]). On the south limb of the Mount Goddard Syncline, the Burr Well Member of Di Bona (1989[1]) consists of mature, medium-grained, swaley cross-stratified, carbonate-cemented sandstone or intraformational conglomerate with edgewise clasts of dolostone, and passes laterally into stromatolitic dolostone (see Fig. 11). A basal lag comprises diapiric detritus. Where the Wearing Dolomite displays such unconformity, it is defined as the Burr Well Member in the sense of Di Bona (1989[1]).

The base of the Wearing Dolomite is interpreted to be a deep water sequence boundary. A maximum flooding surface at the top of the Bunyeroo Formation may coincide with this sequence boundary. The diffuse base of the Wearing Dolomite suggests that early post-depositional dolomitization took place on a sediment-starved hiatal surface. Wavy to parallel lamination and micro-HCS further suggests deposition below storm wave base (e.g., Dyson 1995). The Wearing Dolomite can be traced into the Burr Well Member on the south limb of the Mount Goddard Syncline. The Burr Well Member was deposited in a storm-dominated shoreface to tide-dominated, lagoonal environment. Its sharp, erosional base is a combined sequence boundary/ transgressive surface. The "wall plaster veneer" was deposited on the canyon shoulders. It is interpreted to be coeval with deposition of the Wearing Dolomite and unit W2 of the Wonoka Formation (Fig. 11).

The Wearing Dolomite, together with the Wonoka Formation, is present on the Stuart Shelf where it can be observed in drillcore (e.g., Bopeechee 2 at 367.2 m). A possible Wearing equivalent, only a few centimetres thick, crops out south of Bill's Lookout near the north-western side of Lake Torrens within what was previously interpreted as Yarloo Shale (Johns *et al.* 1966). This suggests that the Wearing Dolomite transgressed the Stuart Shelf prior to deposition of the Wonoka Formation.

Wonoka Formation

The Wearing Dolomite is overlain by unit W2 of the Wonoka Formation, consisting of greyish red, fine-grained sandstone and interbedded calcareous shale. It grades upward into the dominantly calcareous shale of unit W3. The succession represented by units W2 and W3 is overall transgressive. A colour change to greenish limestones in the middle section of unit W3 marks the base of regressive sedimentation in the Wonoka Formation (Fig. 11).

The lithofacies units W3-7 inclusive of the Wonoka Formation display an overall upward sanding trend. It culminates in a thick, storm-dominated, mixed

[1] Eickhoff, K.H. (1988) Geological history and origin of the late Proterozoic Fortress Hill Canyon Complex, Adelaide Geosyncline, S.A. PhD thesis, Flinders University of South Australia (unpub.).

carbonate/siliciclastic succession, commonly displaying HCS (Haines 1988) that was deposited in an inner to middle shelf setting. Units W3-7 of the Wonoka Formation, as interpreted by Haines and other workers, represent regressive sedimentation from initial deposition below storm wave base to deposition above fairweather wave base.

A number of metre-thick, greyish red, medium-grained sandstone beds in unit W7 that are characterised by SCS may represent forced regressive deposits associated with a falling stage systems tract (e.g., Dyson 1996c). In the Angepena Syncline, a disconformity at this stratigraphic level is overlain by a several metre-thick medium-grained sandstone that in many places displays horizontal-planar lamination and SCS. It is interpreted to represent deposition on the lower shoreface in a marine environment. Di Bona & von der Borch (1993) interpreted a lowstand delta at this level in the Umberatana Syncline. Unit W7 is overlain by a succession of shallow marine sandstone and carbonate of tidal and lagoonal origin (Haines 1990) that corresponds to units W8-11. Occasionally, these units can be observed to grade upward into the red shale and sandstone of the Bonney Sandstone, e.g., near Mount Goddard.

The T-R cycle of the Depot Springs Subgroup is an unconformity-bounded, third-order depositional sequence. The canyon fill, represented by units W1, W2 and to a lesser extent W3, constitute the transgressive cycle of the Depot Springs Subgroup. Deposition of unit W1 in the canyon fill was contemporaneous with deposition of the Wearing Dolomite on a sediment-starved hiatal surface. A possible condensed section is represented by unit W3. The middle of this unit corresponds to an abrupt colour change and increase in lime content. A maximum flooding surface may be contained within unit W3 and is therefore equated with a downlap surface. It is overlain by the regressive lithofacies of the Wonoka Formation.

Submarine canyons

The Wearing Dolomite was developed adjacent to a major submarine unconformity on a sediment-starved hiatal surface that corresponds to a combined sequence boundary and major flooding surface (Dyson 1995[1]). It can be observed to pass laterally into slump brecciolas on the shoulders of submarine canyons, e.g., near Beltana Hill, south limb of Angepena Syncline. On the north limb of the Angepena Syncline, the Wearing Dolomite consists of two dolostones that are separated by some 20 m of shale. The upper dolostone overlies the truncated edge of a lower dolostone, suggesting canyon erosion occurred before deposition of the upper dolostone. Furthermore, unit W2 overlies the fill of the Patsy Springs canyon in the Angepena Syncline. Retrogressive slumping on the outer shelf was the precursor to canyon incision, and proceeded up to the level of unit W3 in the Wonoka Formation which marks the turn around from transgressive to regressive sedimentation in the Wonoka Formation (Fig. 11). This interpretation questions the timing of earliest canyon incision expounded by other workers that coincided with deposition of units W3, W4 or W5 (e.g., Haines 1987[2]; Di Bona 1989[3]; Christie-Blick *et al.* 1990, 1995).

Upper sequence boundary

The Bonney Sandstone often displays a sharp though apparently conformable contact with the underlying Wonoka Formation. However, the relationship becomes disconformable in the vicinity of diapirs. Adjacent to some diapirs, e.g., Pinda Diapir on COPLEY and Frome Diapir on PARACHILNA, the Bonney Sandstone displays an unconformable relationship with the Wonoka Formation (Dyson unpub.). Thus, the base of the Bonney Sandstone of the Pound Subgroup is interpreted as a sequence boundary. Dyson (1995[1], 1996a, unpub.) suggested that the development of several prominent unconformities or sequence boundaries within the Umberatana and Wilpena Groups was associated with periods of active and passive diapirism, which in turn was related to major extensional events during break-up of the Neoproterozoic supercontinent.

Discussion

The use of subgroup as an unconformity-bounded unit

The previous use of subgroup in a lithostratigraphic sense has caused problems in regional mapping programmes. A good example is the differentiation of interglacial deposits in the Umberatana Group. They embrace the Farina Subgroup (Coats *et al.* 1969; Thompson 1969) and the Willochra Subgroup (Thomson 1969). The intention of the term Farina Subgroup was to include all relatively deeper water sediments, in contradistinction from the dominantly shallow water redbeds of the Willochra Subgroup (Coats & Preiss 1987). There has been inconsistency in application of the terms, especially in some transitional regions where facies intertongue or are intercalated (Coats & Preiss 1987). The southern portion of PARACHILNA is such a region where a basis for this distinction is warranted. Therefore, a revised stratigraphic nomenclature of the interglacial deposits could be based on differentiation of subgroups as a genetic unit in terms of sequence stratigraphy.

A sequence stratigraphic framework for the Umberatana and Wilpena groups is shown in Fig. 2 and is based on differentiation of subgroups as a genetic unit. An unconformity-bounded sequence incorporates the Tindelpina Shale and Tapley Hill Formation. Similarly, an unconformity-bounded sequence is defined by the top of the Tapley Hill Formation to near the top of the Etina Formation, and an overlying sequence is capped by an unconformity at the base of the Elatina Formation. The Willochra Subgroup previously included the Marinoan glacials of the Elatina Formation (Thomson 1969). The Elatina Formation is capped by dolostone of the Nuccaleena Formation, the basal unit of the Sandison Subgroup. The Sandison Subgroup is unconformably overlain by the Aruhna Subgroup that comprises the Wilcolo Sandstone and Bunyeroo Formation. The Aruhna Subgroup is in turn unconformably overlain by the Wearing Dolomite at the base of the Depot Springs Subgroup (Fig. 2). A similar scheme was proposed for the Kanmantoo Group of Cambrian age (Dyson 1995[1]). More work is required to differentiate genetic units within the Pound Subgroup which contains possibly two unconformity-bounded sequences, with sequence boundaries at the base of the Bonney Sandstone and Ediacara Member of the Rawnsley Quartzite (e.g., Dyson, 1995[2]).

Lithostratigraphic, biostratigraphic and chronostratigraphic units will continue to be used as the basis for most stratigraphic studies. However, the use of unconformity-bounded units is invaluable in basins where the development of stratigraphic units was controlled by tectonic episodes and eustatic sea level cycles. In such basins, e.g., the Adelaide Geosyncline, unconformities pass laterally into correlative conformities where traditional stratigraphy is unlikely to differentiate the lateral and vertical extent of genetic units above and below the sequence boundary. Thus, the use of unconformity-bounded units can contribute to the understanding of the stratigraphy and geologic history of a basin, it can provide the framework for regional stratigraphic framework and it can enable the mapping and expression of stratigraphic concepts for which other stratigraphic units are inadequate (Salvador 1994).

A hierarchy of unconformity-bounded units can be formulated by determining sequence order in a basin. Mitchum & Van Wagoner (1991) proposed a sequence boundary hierarchy of five orders on the frequency of boundary occurrence. Alternatively, Embry (1993) suggested five orders of sequence boundaries based on the nature of the boundary. The latter method is possibly less subjective. However, if every pair of unconformities is used to recognise and name an unconformity-bounded unit such as in the case of the Cardium Formation in the Cretaceous Western Interior Seaway of Canada (Walker 1990), the stratigraphic units would grow unmanageably (Salvador 1994). The use of the subgroup as a depositional sequence of third-order cyclicity thereby usefully limits the establishment of meaningful and useful stratigraphic units on a regional and inter-regional basis.

The significance of dolostones capping Adelaidean sequences

The Wearing Dolomite of the Depot Springs Subgroup was developed adjacent to a major submarine unconformity on a sediment-starved hiatal surface that corresponds to a combined sequence boundary and major flooding surface. There are other dolostones or units containing significant amounts of dolostone that are associated with sequence boundaries in the Umberatana and Wilpena Groups (Fig 2). They are the Warcowie Dolomite, the

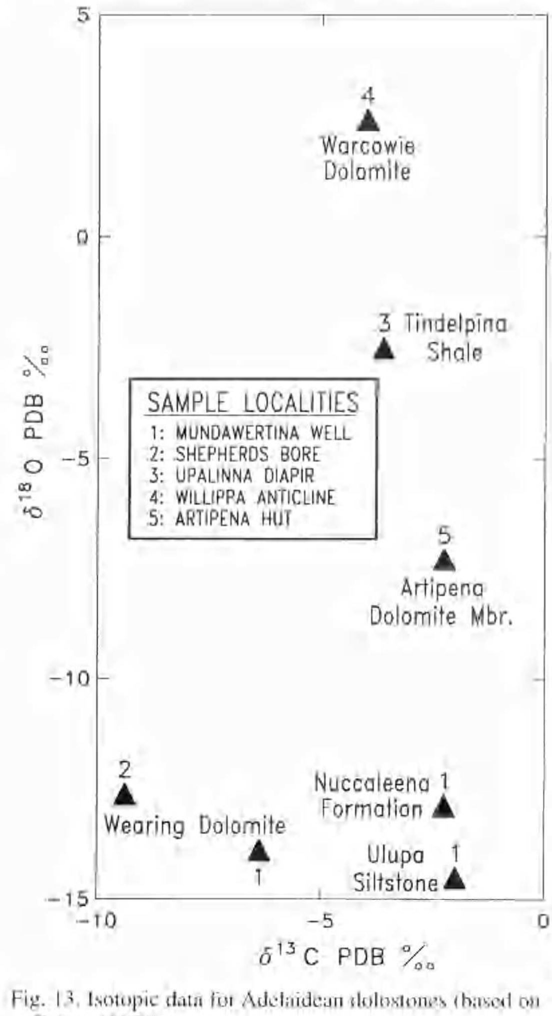

Fig. 13. Isotopic data for Adelaidean dolostones (based on Dyson 1995[1]).

Tindelpina Shale and the Nuccaleena Formation, all of which cap sequences of glacigenic origin. They are commonly referred to as cap dolostones (e.g., Williams 1979). Another dolostone occurs within the lower Enorama Shale and is prominent on south-east PARACHILNA, e.g., between the Willippa Anticline and Martins Well Dome. It is formally referred to here as the Artipena Dolomite Member of the Enorama Shale and a type section is designated 2 km south of Artipena Hut (Fig. 3). Here, it consists of two thin (10-50 cm) dolostones that are separated by 3 m of greyish red shale, and marks the transition from transgressive to overlying regressive sedimentation of the Enorama Shale.

These dolostones of the Umberatana and Wilpena groups display similar characteristics and are interpreted to have been deposited on major flooding surfaces under cold water conditions. Their isotopic data, based on Dyson (1995[1]) in Fig. 13, display two apparent trends. The carbon isotope values show a shift to more negative values with possible increase in water depth, accompanied by an increase in diagenesis. This suggests that the Wearing Dolomite was deposited in greater water depths than the other dolostones and was most susceptible to secondary, post-depositional alteration. The oxygen isotope values show a shift to more negative $\delta^{18}O$ above the stratigraphic level of the Warcowie Dolomite. If $\delta^{18}O$ is sensitive to temperature changes, then it might show a similar trend to relative water depth as suggested by $\delta^{13}C$ (e.g., Baum *et al.* 1994). However, the shift to more negative $\delta^{18}O$ above the Warcowie Dolomite is interpreted to reflect the overall increase in palaeotemperature following the Sturtian glaciation. This interpretation must be viewed with caution, particularly with respect to the Wearing Dolomite, because of overprints associated with secondary, post-depositional alteration. Deposition of the Warcowie Dolomite in a glacigenic environment is suggested by the presence of dropstones (Dyson 1995[1], 1996b). Palaeotemperatures for the Neoproterozoic dolostones are thought to range from 5° C for the Nuccaleena Formation and Wearing Dolomite, to -5° C for the Warcowie Dolomite (C.P. Rao pers. comm. 1995).

Each of the dolostones was deposited on a maximum flooding surface associated with terrigenous starvation. The Milendella Limestone, a carbonate of Cambrian age, occupies a similar stratigraphic position in the Kanmantoo Group. Incised valleys are associated with the Milendella Limestone and Seacliff Sandstone (Dyson & von der Borch 1994; Dyson 1996d). Prograding slope complexes are associated with the Tindelpina Shale. Such units are considered to be the downslope equivalents of incised valleys (Mitchum *et al.* 1993). A pertinent question is why dolostones of the Wearing Dolomite and Warcowie Dolomite do not appear to be associated with incised valleys that show dominantly shallow water features. Major extensional events coinciding with deposition of these units, together with high rates of subsidence, resulted in no fall in relative sea level and precluded development of sandy highstand facies. Instead, dolostones cap relatively deep water sediments of the Bunyeroo Formation and Holowilena Ironstone respectively. Each dolostone is developed on an hiatal surface that represented a period of terrigenous starvation. In each case, this surface can be followed into the submarine unconformity where a major canyon was possibly cut on the outer shelf. In such a setting, a flexural response of the continental margin may have occurred as an isostatic readjustment to canyon erosion (McGinnis *et al.* 1993). For a wide continental shelf, flexural uplift of the outer shelf would not have influenced the position of the shoreline, resulting in an erosional unconformity developed only across the distal shelf (McGinnis *et al.* 1993). The hiatus generated would be greatest across the distal shelf and decrease in a landward direction. Incised valley fills of the Seacliff Sandstone and Milendella Limestone are overall transgressive but display relatively shallow water features at their base. Sequence boundaries at the base of these incised valleys were formed during lesser extensional events when the degree of subsidence was relatively small or, more likely, when the width of the palaeoshelf was relatively narrow. Thus, a fall in relative sea level on the outer shelf resulted in subaerial incised valleys comprising basal fluvial to estuarine deposits.

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